Randomized controlled clinical study of veneered zirconia abutments for single implant crowns: Clinical, histological, and microbiological outcomes

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Abstract: OBJECTIVES To analyze the effect of veneering of the submucosal part of zirconia abutments and the type of retention (cemented vs screw-retained) on clinical, microbiological, and histological outcomes of single-tooth implant crowns. MATERIAL AND METHODS A total of 44 patients with a single missing tooth to be replaced by an implant in the anterior region participated in the study. Implants were randomly assigned to receive zirconia-based CAD/CAM reconstructions using either one of four treatment modalities: cement-retained with submucosal veneering (CR-P), cement-retained without submucosal veneering (CR-W), screw-retained with submucosal veneering (SR-P), and screw-retained without submucosal veneering (SR-W). Clinical parameters were assessed at baseline (after crown insertion), at 6 and 12 months. Histological and microbiological analyses were performed at 6 months. Descriptive statistics and the Kruskal-Wallis test were applied. RESULTS The clinical evaluation revealed, in general, stable peri-implant soft tissues with minimal differences for all measured parameters between the four groups, except for bleeding on probing with the two cemented groups exhibiting higher values at 12 months (35.0% ± 26.5% for CR-W and 25.0% ± 38.8% for CR-P versus 13.1 ± 14.8 for SR-W and 13.0 ± 18.2 for SR-P). The descriptive and semi-quantitative histology showed a trend for a higher inflammatory reaction in the two cemented (a medium to high number of inflammatory cells) compared to the screw-retained groups (low number of inflammatory cells) at 6 months. The microbiological test demonstrated low bacterial counts and a similar distribution in between the groups except for two species (Tannerella forsythia and Peptostreptococcus micros) that were found in higher counts in the cemented groups at 6 months. CONCLUSION Submucosal veneering of zirconia abutments did not negatively affect the health of the peri-implant tissues. The cemented groups, though, did show a clinical and histological trend to higher levels of inflammation.

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Running head: biologic outcomes of ceramic abutments

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D. Thoma, contributed to conception, design, and data analysis, drafted and critically revised the manuscript; A. Gil contributed to data analysis, drafted and critically revised the manuscript; I. Sailer, R. Jung, C. Hämmerle contributed to conception, design, and critically revised the manuscript; S. Mühlemann contributed to conception, design, and data analysis, and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Conflict of interest:

The authors declare that they have no conflict of interest with the contents of this article.

ABSTRACT

Objectives: to analyze the effect of veneering of the submucosal part of zirconia abutments and the type of retention (cemented vs. screw-retained) on clinical, microbiological and histological outcomes of single-tooth implant crowns.

Material and methods: A total 44 patients with a single missing tooth to be replaced by an implant in the anterior region participated in the study. Implants were randomly assigned to receive zirconia-based CAD/CAM reconstructions using either one of four treatment modalities: cement-retained with submucosal veneering (CR-P), cement-retained without submucosal veneering (CR-W), screw-retained with submucosal veneering (SR-P), screw-retained without submucosal veneering (SR-W). Clinical parameters were assessed at baseline (after crown insertion), at 6 and 12 months. Histological and microbiological analyses were performed at 6 months. Descriptive statistics and the Kruskal-Wallis test were applied.

Results: The clinical evaluation revealed, in general, stable peri-implant soft tissues with minimal differences for all measured parameters between the four groups, except for bleeding on probing with the two cemented groups exhibiting higher values at 12 months (35.0 ± 26.5% for CR-W and 25.0 ± 38.8 % for CR-P vs. 13.1 ± 14.8 for SR-W and 13.0 ± 18.2 for SR-P). The descriptive and semi-quantitative histology showed a trend for a higher inflammatory reaction in the two cemented (a medium to high number of inflammatory cells) compared to the screw-retained groups (low number of inflammatory cells) at 6 months. The microbiological test demonstrated low bacterial counts and a similar distribution in between the groups except for

two species (Tannerella forsythia and Peptostreptococcus micros) that were found in higher counts in the cemented groups at 6 months.

*Conclusion S*ubmucosal veneering of zirconia abutments did not negatively affect the health of the peri-implant tissues. The cemented groups, though, did show a clinical and histological trend to higher levels of inflammation.

INTRODUCTION

The choice of the abutment material for implant-supported restorations can profoundly affect the esthetic outcome [1]. Ceramic abutments demonstrated more favorable esthetics in comparison with metal abutments because of their more natural appearance. [2] Zirconia has been used as an abutment material with high survival rates on the restorative and implant level [3,4]. Due to its white property, zirconia abutments offer an advantage in terms of color of the peri-implant mucosa compared to metal abutments, [5,6] predominantly in the presence of a thin peri-implant mucosa (less than 2 mm) [7]. Nevertheless, the colorimetric performance is never equal to that of natural teeth, [8] specifically in thinner biotypes where a discoloration may still be clinically noticeable [9].

Modifications of the abutment characteristics could help address the current limitations. Such modifications of the abutment materials (either by staining or veneering) have been used with various degrees of success [10,11]. The esthetic outcome was dependent on the degree of translucency and brightness of the veneering layer [12]. A reduction in the translucency was shown to offer a higher esthetic benefit [13]. The use of veneered zirconia abutments might therefore be justified from an esthetic point of view. Possible biological and microbiological consequences of placing a veneering ceramic below the mucosal margin are far less investigated. Based on a preclinical study, a greater inflammatory reaction was observed around porcelain veneered metal abutments [14]. This was suggested to be associated with the roughened surface characteristics of these abutment materials, thereby influencing bacterial aggregation and biofilm formation. [15,16]. Clinically, zirconia abutments appear to result in a more favorable peri-implant health as assessed by bleeding on probing compared to metal

abutments [17]. The effect of veneering on biological and microbiological outcomes has not been investigated in detail and is limited to cemented reconstructions [18]. As such, the additional negative/positive influence of the type of retention remains unknown.

The aims of the present study were, therefore, to evaluate the effect of veneering of the submucosal part of zirconia abutments and of the type of retention (cemented vs. screw-retained) on clinical, microbiological and histological outcomes of single-tooth implant crowns.

MATERIAL AND METHODS

Study design and subjects

The study was approved by the local ethical committee (KEK-ZH-Nr.2010-0041) as a randomized controlled clinical trial. The sample size was determined by power calculation using a previous pilot study reporting on esthetic and biological outcomes [12]. After acceptance to participate in the study and signing written informed consents, 44 patients were recruited at the Clinic of Fixed and Removable Prosthodontics and Dental Material Science, University of Zurich, Switzerland between 2011 and 2013. The inclusion criteria applied were successfully osseointegrated implants replacing a single missing tooth, no moderate/severe systemic disease, good oral hygiene, absence of self-reported bruxism, smokers, and nonsmokers.

Prosthetic treatment

The 44 patients received a total of 44 dental implants (OsseoSpeed, ASTRA TECH Implant System, DENTSPLY Implants, Mölndal, Sweden) to replace a single missing tooth in the anterior and premolar area in the maxilla or mandible. All implants were subsequently restored following the same protocol. Implant-supported single-tooth CAD/CAM reconstructions using customized zirconia abutments (Atlantis shade 00, DENTSPLY Implants, Mölndal, Sweden) with all-ceramic crowns were employed. The patients were randomly assigned using sealed envelopes to one of four treatment groups at the time of the final impression:

1) screw-retained reconstruction with non-modified zirconia abutment, directly veneered (SR-W);
2) screw-retained reconstruction with zirconia abutment and submucosal part veneered with pink ceramic (SR-P);

3) cemented reconstruction with non-modified zirconia abutment and all ceramic crown (CR-W);
4) cemented reconstruction with zirconia abutment, submucosal part veneered with pink ceramic and all ceramic crown (CR-P).

The distribution of the implants according to the group, the jaw and the location is described in Table 2.

The thickness of the ceramic veneer (Creation ZI-F, Creation Willi Geller International GmbH; Meiningen, Austria) was a standard 0.5 mm at the level of the abutment-crown junction (for groups CR-P and SR-P).

In the cement retained groups, all-ceramic crowns (emax, Ivoclar Vivadent, Schaan, Liechtenstein) were manufactured and cemented to the abutments with a resin cement (Panavia 21, Kuraray Medical, Kuraray Europe GmbH BU Medical Products Philipp-Reis-Str. 4 65795 Hattersheim amMain Deutschland) after placement of a retraction cord (Ultrapak, Ultradent Products GmbH Am Westhover Berg 30 51149 Köln).

In the screw retained groups, veneering ceramics (Creation ZI-F, Creation Willi Geller International GmbH) were utilized to fabricate one-piece single crowns. These were fixed with a 20 Ncm torque to the implants. The screw access hole was covered with composite material.

All patients that participated in the study were placed into a strict maintenance care program according to their individual needs.

Follow-up examination

Clinical examinations were performed at baseline (one week after the insertion of the crown), at 6 and 12 months after loading. Histological and microbiological analyses were performed at

the 6-month follow-up. Two blinded examiners (one for the histology and one for the clinical and microbiological results) performed the measurements and the data analysis.

Clinical parameters

At 6 and 12 months, plaque index (PI) [19], probing depth (PD), bleeding on probing (BOP), and the width of keratinized mucosa (KM) were recorded around every implant at 6 different sites (except for KM, which was only measured on the buccal side) with the use of a periodontal probe (PCB 12; Hu-Friedy, Leimen, Germany). An endodontic file with a robber stopper was used at 1 mm apical to the mucosal/gingival margin to assess the mucosal thickness (MT) around the implants to the nearest 0.5 mm. BOP and PI were recorded as present (score =1) or absent (score=0). The height of the papillae on the mesial and distal side of the implant crowns and next to the corresponding contra-lateral natural teeth were calculated using the modified papilla index [20].

Microbiological testing

At 6 months, a microbiological analysis was performed. Samples were taken from the mesial and distal sites of the implant and the contra-lateral tooth. The supragingival plaque was first mechanically removed with a curette. Then, the subgingival plaque was collected using sterile paper points inserted into the sulcus for 20 seconds. The paper points were put in tubes and sent for marker pathogen analyses through polymerase chain reaction (PCR) technique (micro-IDent®plus, heico Dent, Wolfhausen, Switzerland). This test provides data on 11 periodonto-pathogenic species and their affiliation to the different “bacterial complexes”. The bacterial

count was categorized as $<10^4$ (-), 10^4 ((+)), $<10^5$ (+), $< 10^6$(++), and $>10^7$ (+++). A count of 10^4 bacteria was the lower detection limit for the test and $>10^7$ was considered a very high bacterial count.

Biopsy harvesting and histological analysis

Soft tissue biopsies were harvested in those cases where the patient gave their consent on the harvesting procedure. For that purpose, an initial sulcular incision following the abutment surface was connected to a second para-marginal incision (at 2mm distance from the sulcus) from the mesio and disto-lingual line angles. The vertical component of the incision extended from the marginal mucosa to the peri-implant crestal bone.

The biopsy specimens were fixated for 48 hours in 4% buffered formalin, then dehydrated and infiltrated with xylol and paraffin (Paraffin 60 Grad Celsius) to finally be cut into 2-5µm thick layers using a paraffin-microtome (MICROM, Medite GmbH, Dietlikon, Switzerland). Hematoxylin-eosin was the method of staining. An optical microscopy (Leica CTR600; Leica, Wetzlar, Germany) was used to assess the sections at a 500 x magnification for descriptive histology with a semi-quantitative analysis. For that purpose, four defined regions of interest (oral epithelium, sulcular epithelium, junctional epithelium, supracrestal connective tissue) were analyzed (Figure 1). A blinded examiner semi-quantitatively analyzed in each region the number of fibroblasts and inflammatory cells following a 4-point scoring scale (1=low degree: low number of fibroblasts/inflammatory cells; to 4=very high degree: very high number of fibroblasts/inflammatory cells).

Statistical analysis

Continuous variables are described with means, standard deviations (sd), medians and quartiles and categorical variables with frequencies or percentages. The comparison of the medians of the 4 groups was performed using the Kruskal-Wallis test because of the small sample sizes and the non-normality of the data distributions. The longitudinal effects were analyzed by the Brunner-Langer nonparametric mixed models. Additional confounder variables were also investigated.

RESULTS

Patients and implants

Forty-four patients (22 males; 22 females) with a mean age of 49.1 years (range 21.3-81.4 years) were included in the study and examined at baseline. At 6 and 12 months, 43 patients were re-examined. One patient could not be contacted despite numerous attempts and did not participate in the follow-up examinations. 10 patients were included in the cement-retained with submucosal veneering (CR-P), 10 in the cement-retained without submucosal veneering (CR-W), 10 in the screw-retained with submucosal veneering (SR-P), and 14 in the screw-retained without submucosal veneering (SR-W).

Clinical examination

All descriptive data is presented in Table 1. Median probing depth (PD) values were not statistically significantly different between the groups at any time-point ($p>0.05$). There was a slight increase in PD between baseline and 12 months in all 4 groups (mean differences ranging from 0.4 to 0.6 mm). The mean PD values in all 4 groups at 12 months ranged between 3.6 ± 0.6 and 4.1 ± 0.6. In all groups, the changes of PD between baseline and 12 months were not significant ($p>0.05$). Intergroup comparisons for changes were not statistically significant ($p>0.05$).

Plaque accumulation (PI) at implant sites slightly increased up to 6 months and then decreased up to 12 months, except for the group CR-P, where it increased from 10.0 ± 17.9% at baseline to 16.6 ± 29.5% at the 12-month follow-up. In all groups, the changes of PI between baseline and 12 months were not significant ($p>0.05$). Intergroup comparisons were not statistically significant ($p>0.05$).

There was a trend for a greater inflammation (as assessed by bleeding on probing) around cemented restorations, both in the CR-W and CR-P group. BOP increased from 10.0 ± 16.1% at baseline to 35.0 ± 26.5% at 12 months in the CR-W group, and from 8.3 ± 8.7% at baseline to 25.0 ± 38.8 % at 12 months in the CR-P group. The changes of BOP between baseline and 12 months were only significant for the group CR-W ($p=0.02$). The time effect (comparing the 3 time-points) was only significant in the CR-W ($p<0.001$). However, intergroup differences tested at the three time-points were not significant ($p>0.05$).

Microbiological analysis

For the majority of the assessed complexes, a similar distribution between the groups and between implant and tooth sites was observed, revealing a relatively low bacterial count for all the different complexes. One species of the red complex (Tannerella forsythia (Tf)), and one species of the orange complex (Peptostreptococcus micros (Pm)) were found in higher counts in the cemented groups compared to the screw retained groups. The bacterial count for Peptostreptococcus micros (Pm) around implant sites is shown in Figure 2.

Descriptive histology

Twenty-eight out of 44 patients agreed for a histological sample at 6 months. The obtained samples belonged to SR-W (n=8), SR-P (n=6), CR-W (n=6) and CR-P (n=8). In general, the peri-implant tissues were healthy and presented with a regular shape. The region of the oral epithelium was characterized by marked rete pegs and a well-organized connective tissue. Large amounts of fibroblast and fibrocytes (part of the granulation tissue) as well as inflammatory cells (monocytes, lymphocytes and macrophages) were present in the junctional

epithelium and the supracrestal connective tissue compartments. No signs of an acute infection were present, but rather a chronic state of inflammation. A positive correlation in terms of the inflammatory reaction was observed: in case of a stronger inflammatory reaction in the apical compartments, a greater inflammation was present even in the compartments of the sulcular and oral epithelium. A gradient with an increasing number of inflammatory cells from the coronal to the apical compartment was observed in all groups except for the SR-P samples. Angiogenesis was present in all compartments. Differences between the groups were mainly observed in the two apical compartments (Figure 3) with the two cemented groups (CR-W, CR-P) revealing a higher number of inflammatory cells compared to the screw-retained groups (SR-W, SR-P). The differences between the native white zirconia abutments were less distinct comparing cemented vs. screw-retained groups, whereas the differences for abutments veneered with pink ceramics was more pronounced between cemented and screw-retained groups.

Semi-quantitative analysis

The overall number of cells increased from the region of the oral epithelium towards the marginal bone crest in all groups except in group SR-P. The differences between the four groups were minimal in the two more coronal compartments, the oral epithelium and the sulcular epithelium, demonstrating a relatively low number of cells (mean scale 1 to 1.5). The largest differences were observed in the two apical compartments with the two cemented groups (CR-W, CR-P) demonstrating a higher overall number of cells. For the screw-retained groups, a higher number of cells was observed for the native zirconia abutments (mean scale 1.7; SR-W) than for the veneered abutments (mean scale 1.2; SR-P). The number of fibroblasts was usually

higher in the oral epithelium compartment and the connective tissue compartment with maximum values observed for veneered cemented reconstructions (mean scale 2.7; CR-P) in the connective tissue compartment. Inflammatory cells were observed in all compartment with mean scales ranging between 1 and 2.7. In both cement-retained groups and the screw-retained white zirconia group, the number of inflammatory cells increased towards the bone crest (Figure 3). The highest numbers were observed for the cemented white zirconia group (mean scale 2.7; CR-W). Screw-retained reconstructions with pink veneering ceramic (SR-P) demonstrated a decreasing number of cells towards the bone crest reaching a mean scale of 1 in the connective tissue compartment.

DISCUSSION

The present study predominantly revealed i) minimal differences for all measured parameters between the four groups; ii) a trend for a higher inflammatory reaction in the two cemented groups as assessed by BOP, the microbiological test, the descriptive and semi-quantitative histology.

Implant-supported restorations employ two different types of retention: cement- or screw-retained. Both types of retention are recommended for implant-supported single crowns [21]. Clinical outcomes may differ, however. Screw-retained reconstructions present more technical complications, but less catastrophic implant failures and less serious biologic complications. Cement-retained reconstructions exhibit significantly more serious biological problems, as reported by a systematic review [22]. This issue with a higher rate of major biological complications may be attributed to an increasing evidence of excess cement present around the implant interface following crown cementation [23-25]. Excess cement has been clinically associated with an increased inflammation (as assessed by bleeding on probing), suppuration [26] and a higher incidence of peri-implant diseases [27]. The present study demonstrated similar results in terms of clinical parameters, with a trend towards more inflammation for cemented reconstructions. The location of the crown margins in the two cemented groups was 0.5-1mm below the peri-implant mucosal margin. Based on an in vitro study [28], even a shallow crown-abutment margin position is prone to excess cement. At the day of crown insertion, radiographs were taken for detection and cement remnants were thoroughly removed using curettes. Still, one might speculate that cement remnants were left undetected, thus resulting in a higher inflammatory reaction.

The choice of the implant abutment material and its macroscopic design influences clinical parameters. Zirconia abutments offer an esthetic advantage [5], but their biological response has been a matter of discussion. A recent systematic review showed that titanium abutments developed a higher inflammatory reaction compared to zirconia abutments [17]. The macroscopic design, however, did not show any difference in soft tissue inflammation. No studies using veneered abutment were included though. The results of the present study failed to show a difference in probing depth in between the submucosal veneered and then non-modified zirconia abutments. However, the non-modified zirconia abutments revealed slightly higher bleeding on probing scores. This also could be attributed to the rougher surface of the abutments in the SR-W and CR-W groups compared to the submucosally veneered groups. The optimal roughness of zirconia abutments to obtain peri-implant health, reduce plaque accumulation and obtain a long-term tight seal, is unknown today.

Bleeding on probing around implants can be a result of inflammation due to bacterial colonization, penetration of the soft tissue seal around the implant or presence of cement remnants. It is challenging to clinically distinguish one from another. Histological and microbiological analyses should provide further information. Histologically, there is evidence from preclinical studies [14,29] of an increased presence of inflammatory cells in the junctional epithelium surrounding implants, possibly due to the microbial challenge caused by the development of a biofilm around the implant. There is very limited literature, though, looking at the soft tissue response to zirconia abutments. [30]. The descriptive histology of the present study revealed a chronic state of inflammation where a gradient with an increasing number of inflammatory cells from the coronal to the apical compartment was observed. Such a reaction

could be due to the microbiota present in the biofilm around the implant, as shown in the microbiological analysis. More specifically, the cemented groups had a higher number of inflammatory infiltrate compared to the screw-retained ones. Cement can harbor microorganisms and prevent their proper removal, thus eliciting an inflammatory reaction. This rare histological finding was also shown in a recent study with a remarkable degree of inflammation at cemented restorations [18].

From a microbiological point of view, evidence revealed that a wide diversity of microorganisms colonizes the healthy peri-implant pockets, ranging from gram positive streptococci and rods to gram negative anaerobic species. [31].

This observation of peri-implant tissues harboring a wide range of bacteria was confirmed in the present study. The numbers of microbiota, however, were low and no evident differences were observed between the groups. The count for the majority of pathogens was below the threshold value of $10^{4.}$ There were only two species (Tannerella forsythia (Tf)) and (Peptostreptococcus micros (Pm)) from the red and orange complex respectively, that were found in slightly higher counts. The presence of this particular microbiota may explain the concentrated inflammatory infiltrate around cemented restorations, where this bacteria were present in higher counts. This finding has also been reported in a recent study [32], where both bacterial species previously described where found in higher numbers in the sulci of cemented restorations. It was also shown that cemented restorations exhibited a higher permeability to most microbes. Nevertheless, the presence of cement remnants and specific microbiota did not necessarily translate in the development of peri-implant disease, since additional triggering risk factors might be needed.

CONCLUSIONS

In conclusion, submucosal veneering of zirconia abutments did not negatively affect the health of the peri-implant tissues. Both screw-retained and cemented groups resulted in stable clinical results at one year. The cemented groups, though, did show a clinical and histological trend to higher levels of inflammation.

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Figure Legends:

Table 1. Clinical outcomes: probing depth (PD), plaque index (PI), bleeding on probing (BOP), mucosal thickness (MT), width of keratinized mucosa (KM); implant cement-retained pink (CR-P), implant cement-retained white (CR-W), implant screw-retained pink (SR-P), implant screw-retained white (SR-W); SD, Standard deviation. *Statistical significance

Table 2. Implant distribution with implant group, jaw and location in all 44 patients. implant cement-retained pink (CR-P), implant cement-retained white (CR-W), implant screw-retained pink (SR-P), implant screw-retained white (SR-W).

Figure 1: Histological analysis of SR-P group, showing 4 regions of interest: A) oral epithelium; B) sulcular epithelium; C) junctional epithelium; and D) supracrestal connective tissue.

Figure 2: Bacterial count for Peptostreptococcus micros (Pm) around implant sites: implant cement-retained pink (CR-P), implant cement-retained white (CR-W), implant screw-retained pink (SR-P), implant screw-retained white (SR-W). (-) bacterial count below detection limit ($<10^4$); ((+)) bacterial count at the detection limit (10^4); (+) bacterial count slightly increased ($<10^5$); (++) bacterial count substantially increased ($<10^6$); (+++) very high bacterial count ($>10^7$). Y-axis represents the percentage (%) of sites that harbor each bacterial count.

Figure 3: Histological analysis comparing group CR-W (left) and SR-P (right), showing the inflammatory cells of compartments C and D. Notice the presence of a clear inflammatory infiltrate in the CR-W group compared to the SR-P group in the junctional epithelium compartment (C) and in the supracrestal connective tissue compartment (D). Cells are marked in yellow (fibroblasts) and in green (inflammatory cells).

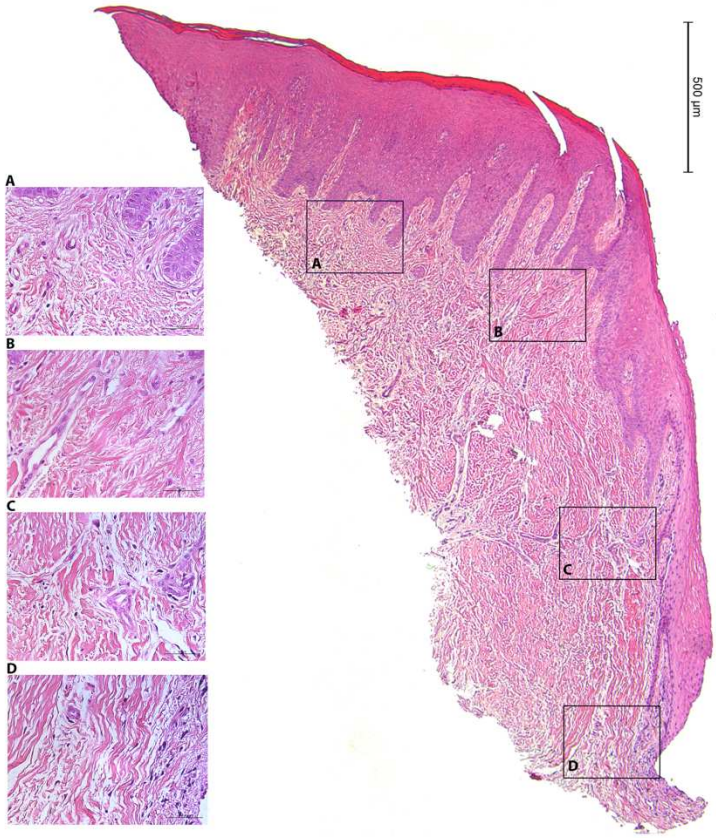

Figure 1

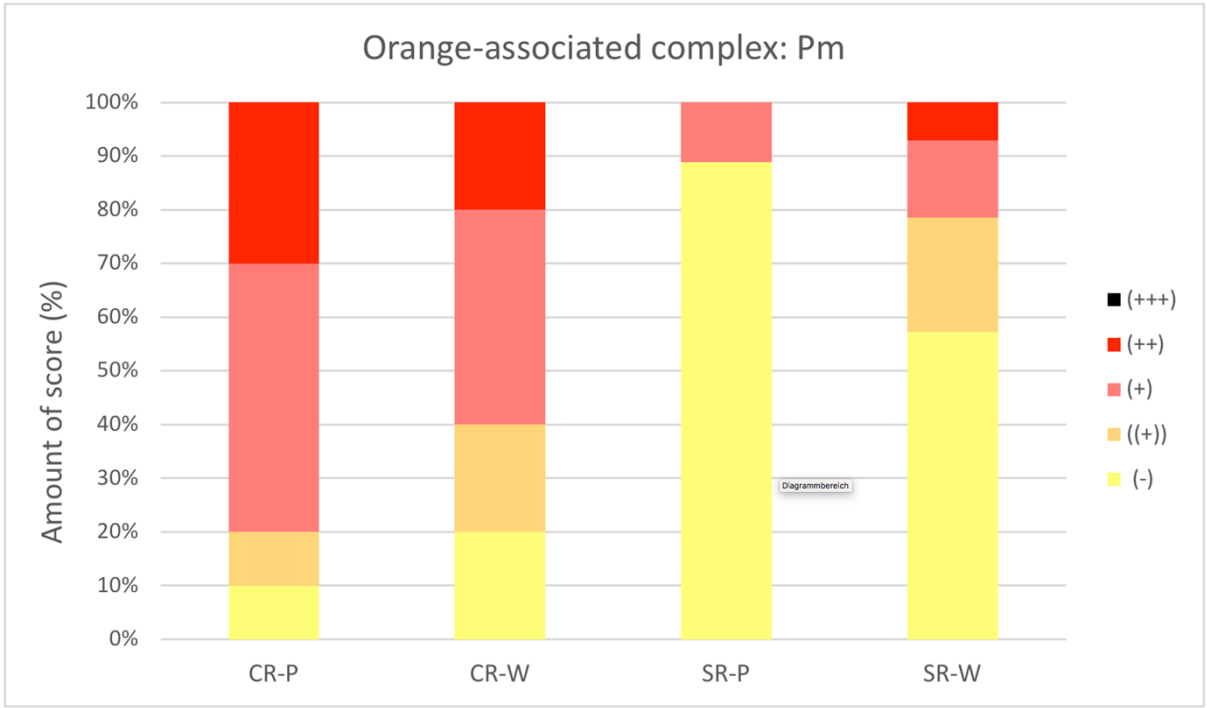

Figure 2

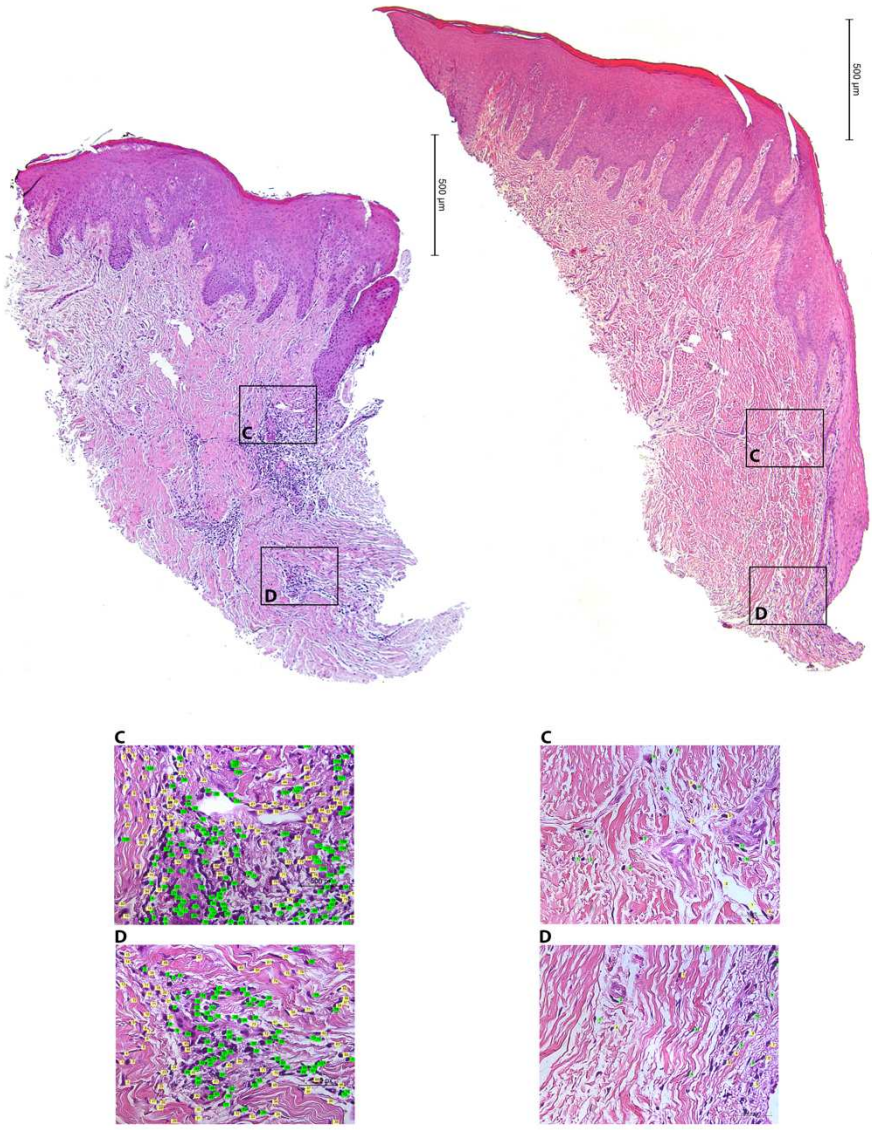

Figure 3

FIGURES AND TABLES

Table 1

	Baseline	6 months	12 months	Difference 12 months-baseline	Difference 12 months to baseline	all 3 time-points
PD (mm)	mean ± SD, median	mean ± SD, median	mean ± SD, median	mean ± SD, median	p-value	p-value
CR-P	3.6 ± 0.8, 3.0	3.7 ± 1.4, 4.0	4.0 ± 1.1, 4.0	0.4 ± 0.5, 0.0	0.25	0.19
CR-W	3.2 ± 0.6, 3.0	3.3 ± 1.2, 3.0	3.8 ± 1.1, 3.5	0.6 ± 1.2, 0.5	0.17	0.21
SR-P	3.5 ± 0.5, 3.5	3.7 ± 0.5, 4.0	4.1 ± 0.6, 4.0	0.6 ± 0.7, 0.5	0.13	0.07
SR-W	3.5 ± 0.6, 3.5	3.4 ± 0.8,3.0	3.6 ± 0.6, 3.5	0.0 ± 0.6, 0.0	1.00	0.70
PI (%)						
CR-P	10.0±17.9, 0.0	15.0±21.4, 0.0	16.6±29.5, 0.0	4.6 ± 36.5, 0.0	1.00	0.84
CR-W	0.0±0.0, 0.0	10.0±17.9 ,0.0	6.6±11.7, 0.0	6.7 ± 11.7, 0.0	0.25	0.07
SR-P	0.0±0.0, 0.0	7.4±12.1, 0.0	3.7±11.1, 0.0	3.7 ± 11.1, 0.0	1.00	0.19
SR-W	2.4±6.0, 0.0	14.3±5.8,16.7	8.3±18.2, 0.0	6.0 ±19.2, 0.0	0.50	0.02
BOP (%)						
CR-P	8.3 ± 8.7, 8.3	15.0±20.0, 8.3	25.0±38.8, 0.0	16.7 ± 35.6, 0.0	0.31	0.78
CR-W	10.0±16.1, 0.0	33.3±27.2, 41.7	35.0±26.6, 25.0	25.0 ± 25.2, 16.7	0.02	<0.001
SR-P	13.0±20.0, 0.0	9.3±12.1, 0.0	13.0±18.2, 0.0	0.0 ± 31.2, 0.0	1.00	0.96
SR-W	10.7±22.2, 0.0	15.5±17.8, 8.3	13.1±14.9, 16.7	2.4 ± 28.4, 16.7	0.13	0.54
KM (mm)						
CR-P	4.0 ± 1.4, 4.0	3.6 ± 1.2, 4.0	4.2 ± 1.2, 4.0	0.0 ± 0.7, 0.0	1.00	0.19
CR-W	3.3 ± 1.1, 3.0	3.0 ± 1.6, 3.0	2.9 ± 1.4, 3.0	-0.3 ± 0.9, -0.5	0.69	0.22
SR-P	2.3 ± 1.0, 2.0	2.4 ± 1.0, 2.25	2.6 ± 1.3, 2.0	0.3 ± 1.0, 0.0	0.56	0.54
SR-W	3.2 ± 1.6 3.5	3.2 ± 1.7, 4.0	3.4 ± 1.4, 3.5	0.2 ± 1.1, 0.2	0.66	0.85
MT (mm)						
CR-P	2.5 ± 0.4, 2.5	2.3 ± 0.6, 2.0	2.7 ± 0.8, 3.0	0.3 ± 0.7, 0.0	0.50	0.17
CR-W	2.2 ± 0.9, 2.5	2.1 ± 0.7, 2.25	2.4 ± 0.5, 2.5	0.2 ± 0.7, 0.5	0.45	0.34
SR-P	1.7 ± 1.1, 1.5	2.1 ± 0.6, 2.0	2.4 ± 0.4, 2.5	0.6 ± 1.1, 0.5	0.16	0.07
SR-W	2.1 ± 0.8, 2.0	2.0 ± 0.7, 2.0	2.0 ± 0.7, 2.0	0.1 ± 1.0, 0.3	0.39	0.97

Table 2

Subject number	Group	Jaw	Location
1	CR-P	Maxilla	25
2	CR-W	Maxilla	25
3	SR-W	Mandible	44
4	SR-W	Maxilla	12
5	SR-W	Maxilla	15
6	CR-P	Maxilla	24
7	SR-P	Maxilla	24
8	SR-W	Maxilla	22
9	SR-P	Mandible	35
10	CR-P	Maxilla	21
11	SR-W	Maxilla	12
12	SR-P	Mandible	35
13	CR-W	Maxilla	14
14	CR-P	Maxilla	14
15	SR-P	Maxilla	15
16	SR-W	Maxilla	14
17	CR-P	Maxilla	15
18	CR-W	Mandible	35
19	SR-W	Maxilla	15
20	CR-W	Maxilla	24
21	SR-P	Mandible	45
22	SR-W	Maxilla	14
23	CR-P	Mandible	45
24	CR-W	Maxilla	15
25	SR-W	Maxilla	22
26	CR-W	Maxilla	24
27	SR-P	Maxilla	14
28	CR-P	Maxilla	22
29	SR-W	Mandible	33
30	SR-P	Maxilla	14
31	CR-W	Maxilla	24
32	CR-P	Maxilla	21
33	SR-P	Maxilla	25
34	CR-W	Mandible	35
35	SR-W	Maxilla	15
36	CR-P	Maxilla	11

37	CR-P	Maxilla	25
38	CR-W	Maxilla	24
39	SR-P	Maxilla	24
40	CR-W	Mandible	45
41	SR-W	Maxilla	11
42	SR-P	Mandible	34
43	SR-W	Maxilla	21
44	SR-W	Mandible	45